Unit 7 – Synchronous Motor Drives

Syllabus

- Synchronous motor control
- Analysis with electronic commutation
- Concept of self-control
  - ✓ Stator current control
  - ✓ Marginal angle control

References

1. Rashid. M. H., “ Power Electronics – circuits, Devices and Applications”, Prentice Hall India, New Delhi, 2013.

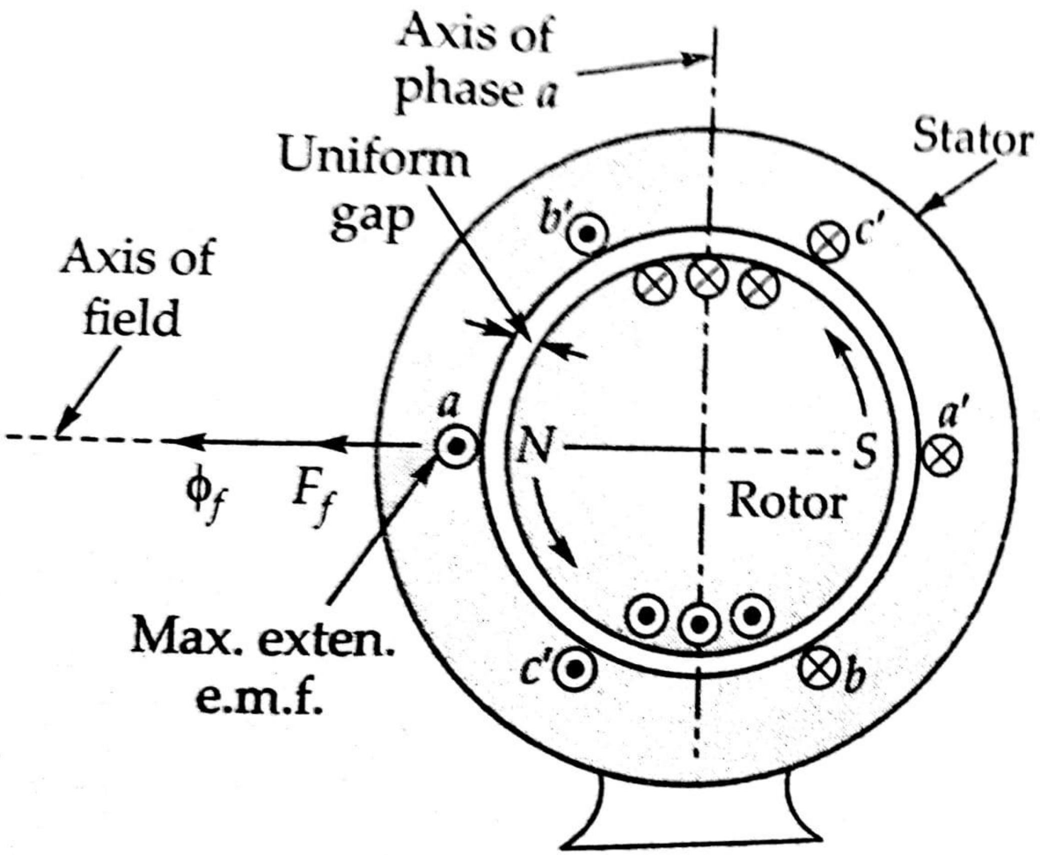
2. P. C. Sen., “ Principles of electric machines and power electronics”, John Wiley and Sons, 2013.

3. G.k Dubey., “ Power Semiconductor Controlled Drives”, Prentice Hall, 1989

Synchronous Motor

- A synchronous motor is a constant-speed machine and always rotates with zero slip at the synchronous speed, which depends on the frequency and the number of poles, as given by,

$$\omega_s = \frac{2\omega}{p} \quad \text{or} \quad N_s = \frac{120f}{p}$$



- Synchronous motors have a polyphase winding on the stator, also known as armature, and a field winding carrying a dc current on the rotor.

- There are two mmfs involved: one due to the field current and the other due to the armature current. The resultant mmf produces the torque. The angle between the two EMFs is called torque angle.

- The maximum constant torque under which a motor will accelerate from rest to approximate normal speed (near Synchronous speed) is known as Pull in torque. It is around 95% of full load torque.

- Maximum torque is developed at 90° torque angle. Beyond which the machine fails to run at synchronous speed (speed becomes zero, N = 0). This torque is called pull out torque.

$$T_{p_0} = \frac{3 \times V_a \times V_f}{X_s \omega_s}$$

Where :

V_a is the armature voltage or input voltage

V_f is the field excitation voltage which is given by,

$$V_f = V_a - I_a (R_s + jX_s)$$

I_a is the armature current

Rs is the stator resistance

X_s is the stator reactance

ω_s is syncronous speed [rad/sec]

- With cycloconverters and inverters the applications of synchronous motors in variable speed drives are widening.

- Applications of high speed synchronous motors include fans, blowers, dc generators, line shafts, centrifugal pumps, compressors, reciprocating pumps, rubber and paper mills

Compressor

Blower

Centrifugal Pump

Problems

A three-phase, 415-V, 50-Hz, four-pole, Y-connected motor rotates synchronous speed. The reactance of such motor Xs = 3 Ω and the armature resistance is negligible. The load torque, which is proportional to the speed squared, is T_L = 210 Nm at 1500 rpm. The PF is maintained at unity by field control and the voltage-to-frequency ratio is kept constant at the rated value. If the inverter frequency is 40 Hz and the motor speed is 1200 rpm, calculate (a) the input voltage, (b) the armature current, (c) the excitation voltage, (d) the torque angle, (e) Pull out torque, (f) Pull in torque

GIVEN: Power factor = PF = cosϕ = 1, Number of poles = 4

$$\text{Rated phase voltage} = \text{base voltage} = V_b = \frac{415}{\sqrt{3}} = 239.6\ \text{V}$$

$$\text{Synchronous Speed} = \text{Base speed}\ , N_b = \frac{120\times f}{P} = \frac{120\times 50}{4} = 1500\ \text{rpm}$$

$$\omega_b = \frac{2\times\pi\times 1500}{60} = 157.08\ \text{rad/s}$$

$$\frac{\text{Base Voltage}}{\text{Base speed}} = d = \frac{V_b}{\omega_b} = \frac{239.6}{157.08} = 1.525$$

At 1500 rpm, T_L=210 Nm

Thus, at 1200rpm, $T_L = 210 \times \left(\frac{1200}{1500}\right)^2$ (as $T_L \propto N^2$)

Which gives, $T_L = 134.4\,\text{Nm}$

1200 rpm in rad/s is equal to 125.66 rad/s

Hence the output power $P_0 = 134.4 \times 125.66 = 16,888.7\,\text{W}$

(a) Input voltage at 1200 rpm,

$$v_a = d\omega = 1.525 \times 125.66 = 191.63\,\text{V}$$

(b) The armature current

The output power, $P_0 = 3V_aI_aPF$ from which

$$I_a = \frac{P_0}{3 \times V_a} = \frac{16888.7}{3 \times 191.63} = 29.38\,\text{A}$$

(c) The excitation voltage, is

$$V_f = V_a - I_a(R_s + jX_s) = 191.63 - 29.38(j3)$$
$$= 210.93\angle -24.70^\circ$$

(d) The torque angle, $\delta = -24.70^\circ$

(e) Pull out Torque is $T_{p_0} = \frac{3 \times V_a \times V_f}{X_s\omega_s} = \frac{3 \times 191.63 \times 210.93}{3 \times 125.66}$

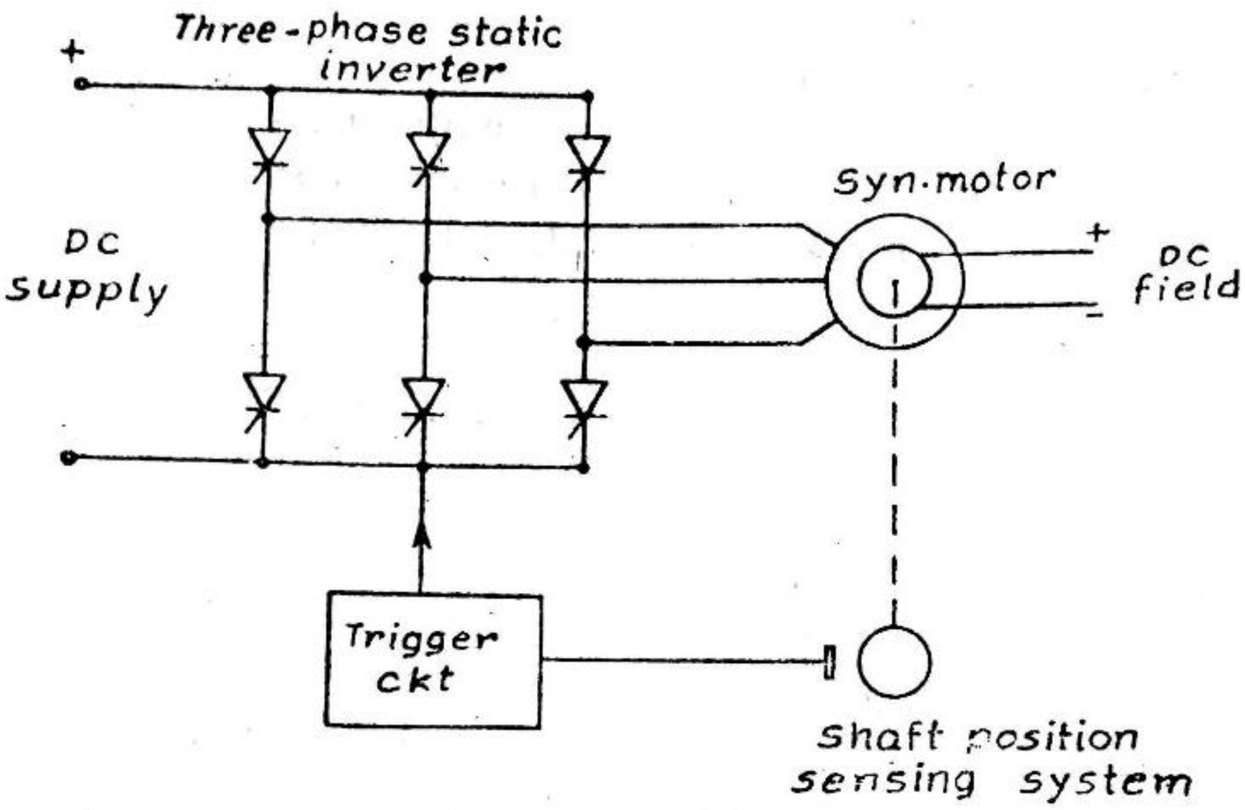
$$= 321.66\,\text{Nm}$$

(f) Pull in Torque is the 95% of the load torque at (1200 rpm),

$$= 134.4 \times 0.95 = 127.68\,\text{Nm}$$

Electronically Commutated Synchronous Motor

- In synchronous motor, DC supply is given to the rotor coils through slip rings and commutator brush arrangement.
- When the stator (or) the armature is fed with inverter providing pulses in synchronism with respect the rotor position (through position feedback signals), the synchronous motor can be called as a commutator less synchronous motor
- The commutatorless synchronous motor arrangement is shown in the figure. A six step inverter with the rotor position sensing unit is called as an electronic commutator.
- The switching or firing pulses to the inverter are provided based on the rotor position for smooth operation of the motor.

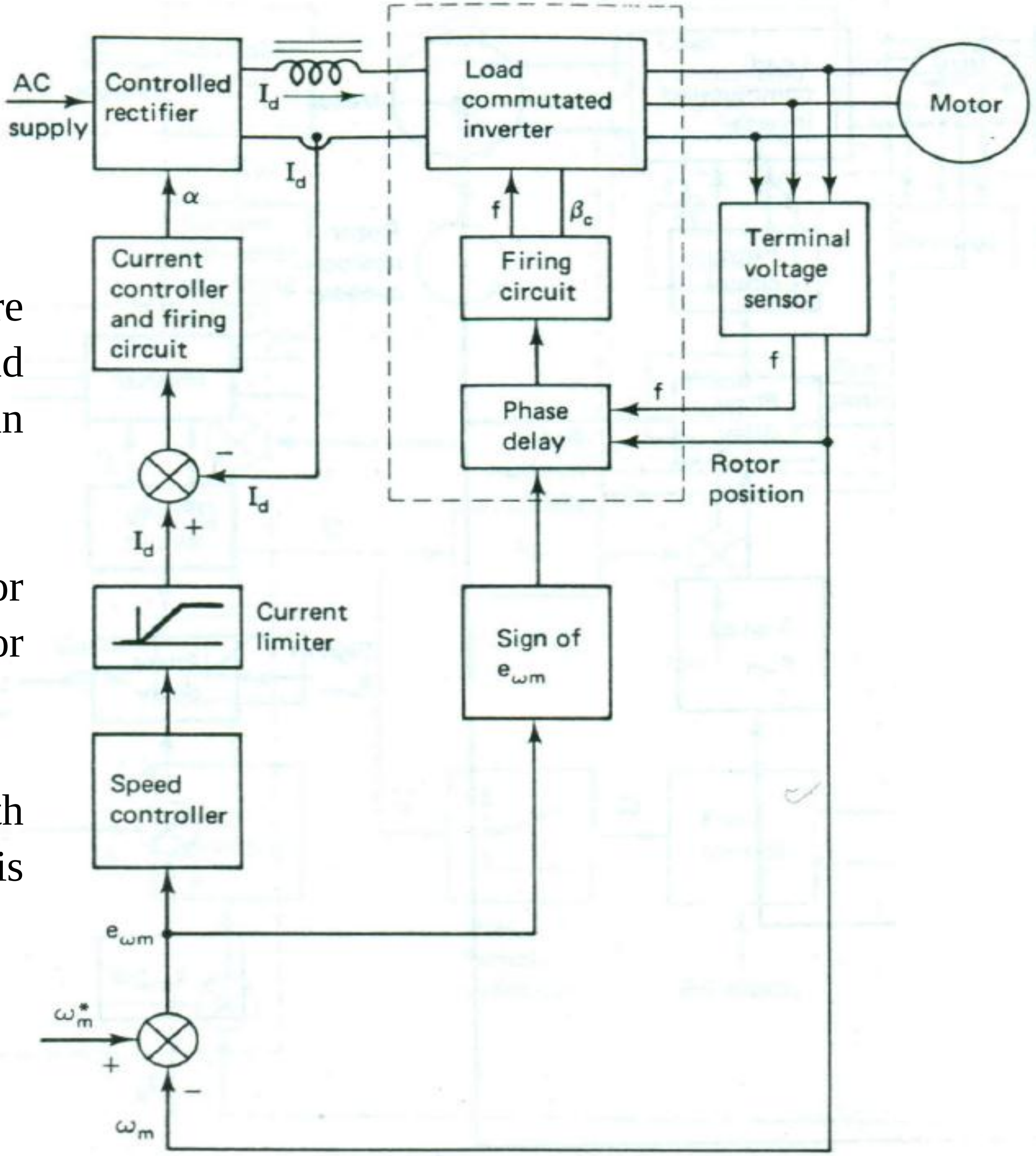


Self Controlled Synchronous Motor Drives with stator current control

- Self-controlled synchronous motor drives are popularly known as commutatorless AC drives and fed from a AC supply through an inverter or from an ac supply though a cycloconverter.

- The firing pulses may be derived either from the rotor position encoder or machine terminal voltage sensor and any one of the control strategies.

- The drive employs an inner current control loop with an outer speed loop. The inner current control loop is nothing but a closed-loop current source.

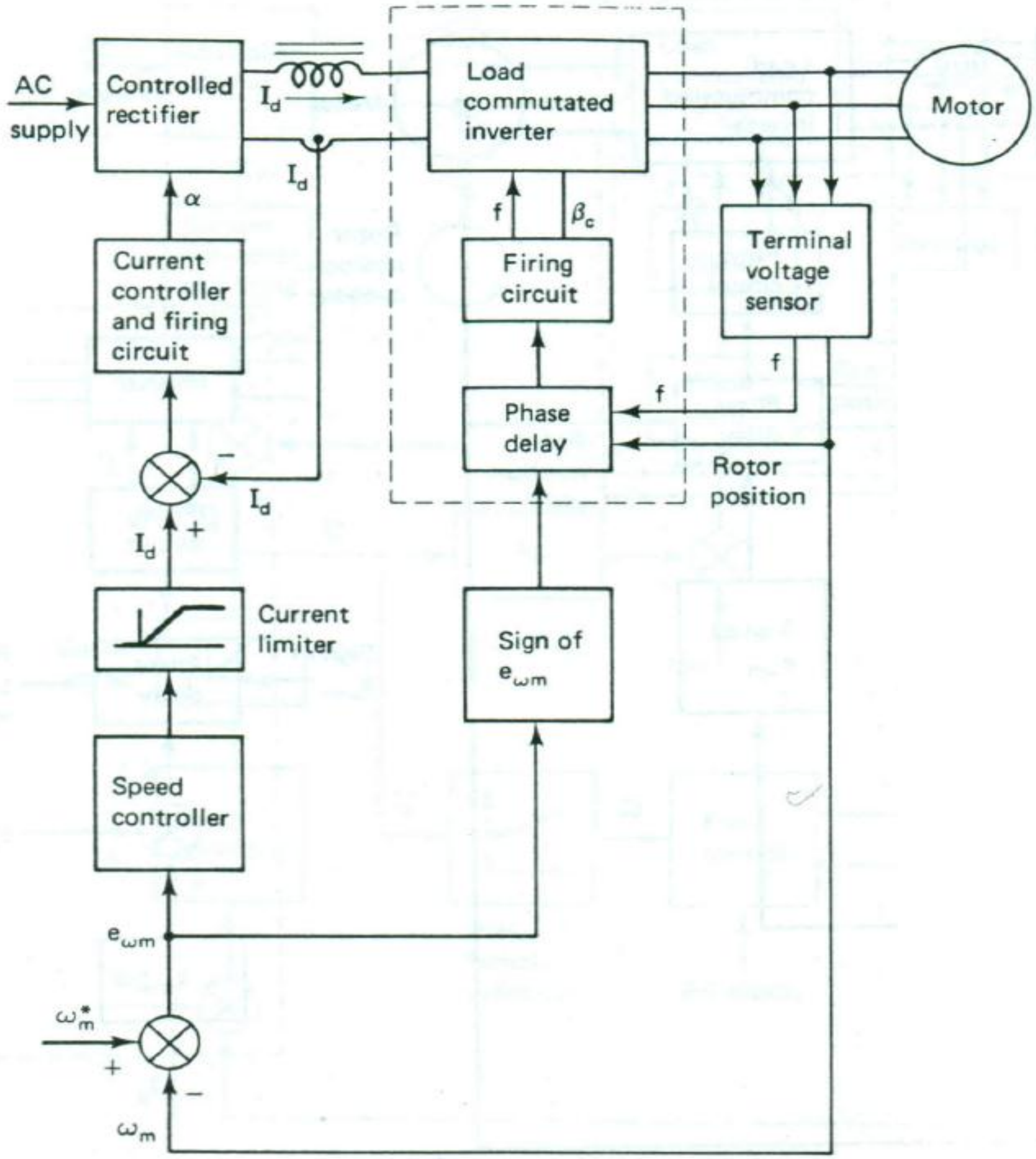


- The terminal voltage sensor generates reference pulses of the same frequency as the machine induced voltage.

- The phase delay circuit shifts the reference pulses suitably to obtain control at a constant commutation lead angle, β_c.

- Depending on the sign of the speed error $e_{\omega m}$, β_c is set to provide motoring or braking operation.

- The speed controller and current limiter set the DC link current command I_d at the maximum allowable value.

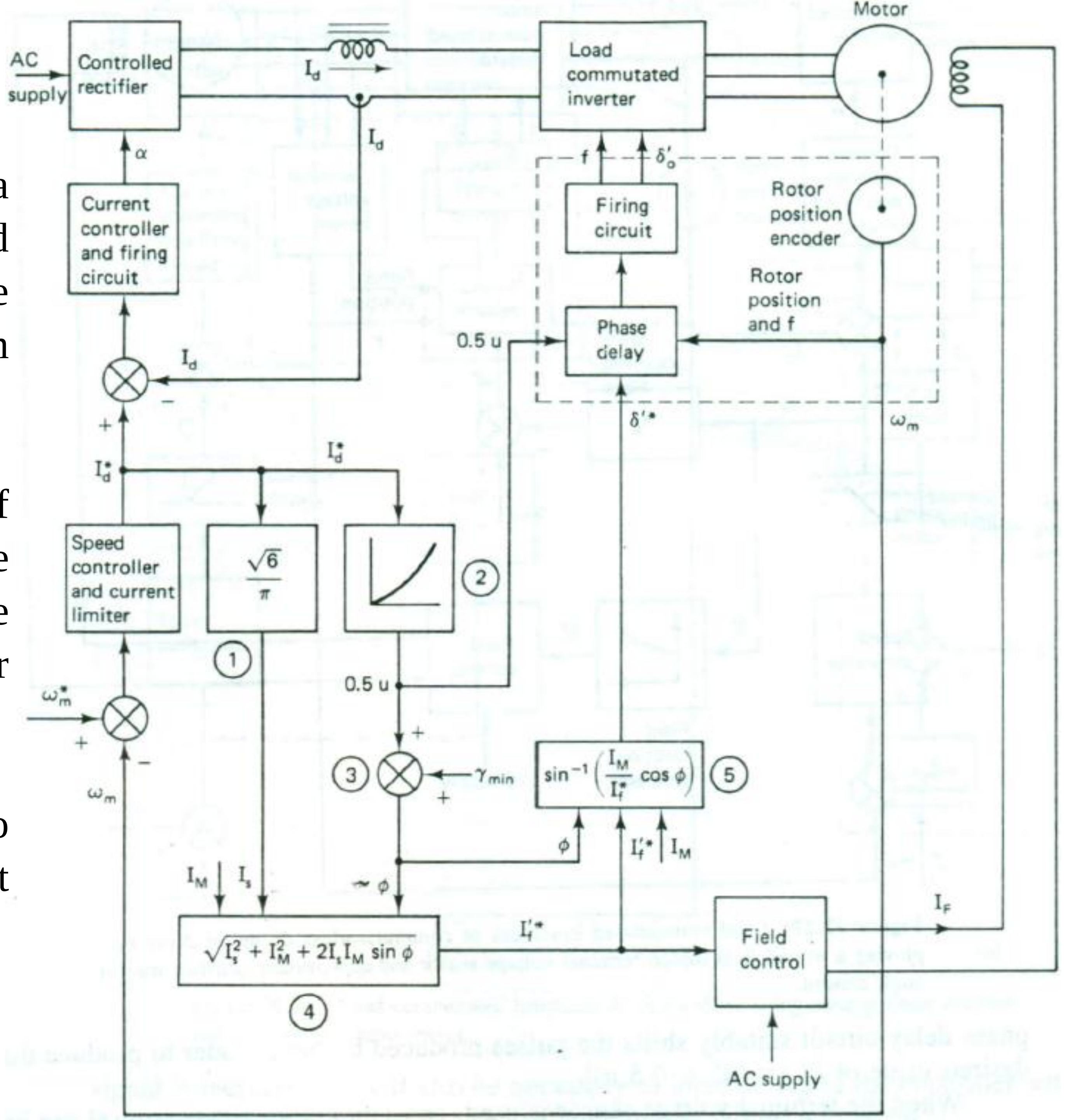


Self Controlled Synchronous Motor Drives with Marginal angle control

- The constant **marginal-angle** control is a triggering control scheme applied to a load commutated inverter to eliminate the commutation failure and to increase the system power factor.

- The commutation Marginal angle control of Synchronous Motors is defined as the angle measured from the end of commutation to the crossing of the phase voltage which was under commutation (natural firing instant).

- The block diagram has an arrangement to produce constant flux operation and constant marginal angle control.



- From the value of de link current command, command dc-link current I_d‘ and stator current I_s are produced by blocks (1) and (2), respectively.

- In block (4), command field current I_f' is calculated from the known values of command stator current I_s', flux ϕ and magnetizing current, I_M.

- The magnetizing current I_M' is held constant at its rated value I_M to keep the flux constant.

- The phase delay circuit suitably shifts the pulses produced by the encoder to produce the desired value of torque angle, δ_o'.

- Self controlled synchronous motor drives are used in medium power, high-power and very high power (tens of megawatts) drives, and high-speed drives, such as compressors, extruders, induced and forced draft fans, blowers, conveyers, aircraft test facilities, steel rolling mills, large ship propulsion, main line traction, flywheel energy storage, and so on.

- They have also been used for the starting of large synchronous machine in gas turbine and pumped storage plants. High-power drives usually employ rectifiers with higher pulse numbers (12 or more), to minimize torque pulsations. The converter voltage ratings are also high so that efficient high voltage motors can be employed.

Thank You